Intern. J. Neuroscience, 112:65–79, 2002
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0020-7454/02 $12.00 + .00

HEMISPHERIC ASYMMETRY (LATERALIZATION) IN ELECTROENCEPHALOGRAPHIC ACTIVITY WHILE VIEWING FAMILIAR AND UNFAMILIAR PATTERNS FROM KIMURA FIGURES

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Kimura Recurring Figures were presented after the priming trial to the upper or lower, left or right, tachistoscopic fields while monopolar electroencephalographic activity was measured over the left and right parietal, occipital, and temporal lobes for 9 men and 9 women. The relative proportions of alpha rhythms during the 2 sec after each of 64 presentations were employed as the primary measure. The powerful asymmetry in electroencephalographic activity, manifested as a paucity of alpha activity over the right temporal lobe compared to the left temporal lobe, was not observed for the parietal or occipital regions. There was conspicuously more relative activity over the parietal and occipital lobes, but not over the temporal lobes, during presentations of the familiar figures compared to the unfamiliar figures. Several interactions—explaining more than 25% of the variance—between gender, left and right hemispheric EEG activity, and visual quadrants were consistent with lateralization of function and gender differences in functional brain organization.

Keywords electroencephalogram, Kimura figures, occipital lobe, parietal lobe, spatial patterns, temporal lobe, visual fields

Thanks to the Electroencephalography Laboratory at the Sudbury General Hospital for donating the Beckman EEG and to Stan Koren and Sandra Tiller for technical support.

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Functional hemispheric asymmetry during processing of components of visual information has been considered a robust phenomenon (Gordon & Carmon, 1976; Hellige, 1995). The two hemispheres appear to extract different features from the visual stimuli that form object representations (Kosslyn et al., 1989). Whereas the left hemisphere responds to small components of visual stimuli with higher spatial frequencies, the right hemisphere may be specialized to extract global forms with lower spatial frequencies (Brown & Kosslyn, 1995).

Recognition and memory of visuospatial patterns have been frequently attributed to functions that emphasize the right occipitoparietal and right temporal lobes, respectively. The present study was designed to infer the role of the right parieto-occipital regions in the perception of unfamiliar or novel visuospatial stimuli and the role of the right temporal lobes in the processes of remembering these complex spatial patterns. Our inference was derived from the electroencephalographic activity; specifically, the presence of easily identifiable alpha rhythms during the presentation of the stimuli.

We employed Kimura's complex figures (Kimura, 1986) as stimuli because they contained both familiar and nonfamiliar sequences of both geometric and irregular visuospatial patterns. Irregular or abstract patterns are more difficult to verbally label. In order to help localize the degree of cerebral lateralization of any effect, we employed a traditional (tachistoscopic) method. Consequently, the stimulus figures were presented to either the upper or lower, and either right or left, visual fields while the electroencephalographic recordings were measured.

METHODS

Subjects

A total of 9 men and 9 women, 19 to 25 years of age, volunteered as subjects. All subjects preferred their right hand for writing and were rewarded for participation by a 2% bonus mark for an introductory psychology course within which they were enrolled.

PROCEDURE

Each subject sat upright in a comfortable chair and placed his or her face against the viewing mask of a Gerbrands tachistoscope. Silver-silver electrodes were attached by EC-2 (Grass) cream to the scalp. The placements were T4, P6, 02, T3, P5, and 01 with a common ground to the ear. The electrodes were attached to a Beckman 8-channel electroencephalograph. The experiment began after the appropriate resistivity for all electrodes had been verified. The importance of minimal physical movement, in order to minimize interference with electroencephalographic recordings, was emphasized.

The subjects were instructed to maintain focus during the entire experiment on a small cross that was present in the middle of the visual field within the tachistoscope. They were told not to allow their eyes to wander around the viewing screen and that the cross would disappear with the presentation of each slide. All stimuli were presented within either the upper or lower, left or right, quadrants of the tachistoscope through 35 mm slides from a slide projector controlled by a personal computer.

The subjects were instructed to only view the first 8 slides and to not respond. In addition, subjects were told that the experiment would begin 5 s after the presentation of the stimulus "Recurring Figures," a reminder that the subject must now respond with his or her index finger on a keyboard after each stimulus to indicate if the stimulus was familiar (one of the 8 figures in the priming phase) or not familiar (not one of the figures seen in the priming phase).

During the priming phase of the experiment, 8 different patterns (4 geometric and 4 abstract shapes), according to Kimura's (1986) instructions, were presented for 2 s each. All stimuli were presented in the central field. These 8 priming slides served as the recurring stimuli.

During the recognition phase of the experiment, after the presentation of the slide "Recurring Figures," the 8 priming slides were presented. One of the 4 geometric shapes was presented in each of the 4 quadrants and one of the abstract shapes was presented in each of the 4 quadrants. A given stimulus always appeared in the same quadrant. Each slide was presented 4 times for 5 s each time. This meant that each subject was exposed to the familiar stimuli 32 times.

The remaining 32 stimuli contained unfamiliar or novel patterns from the Kimura collection. Of these stimuli 16 were geometric figures while the other 16 were abstract figures. A total of 4 of each of these figures, geometric and abstract, were presented in each of the four quadrants of the visual field. Each of the unfamiliar stimuli was presented only once for 5 s.

The total numbers of stimuli presented during the entire experiment was 64 and each slide was presented for 5 s. The order of presentation with respect to geometric or abstract figure, as well as the quadrant of presentation, were determined before the experiment by random selection. All subjects received the same order of presentation. The presentation in real time for each slide was indicated mechanically on the EEG paper by the second author who sat behind the subject and monitored the responses and the equipment.

The record of each subject was analyzed by a technician who was blind to the condition of the stimulus figures and the experiment. The presence of alpha rhythms (defined as rhythmic, oscillating patterns between 8 and 13 Hz) within more than 50% of the record for the first 2 s after the presentation of the stimulus was measured for each of the 6 leads (3 left, 3 right hemisphere) for each stimulus figure. Therefore, each 2-s increment after the presentation of a stimulus had a value of 0 or 1. We called this increment an alpha period. The duration of 2 s had been selected because it was the typical time between the presentation of the stimulus and the major movement to press one of the two keys that indicated if the figure was familiar or not familiar.

The interrater reliability, based upon Spearman rho correlations for 100 separate measurements for two technicians, was 0.95. The data were loaded onto a Vax 4000 computer and analyzed by the MANOVA program using SPSS software. The percentages of raw alpha periods were calculated by multiplying the mean of the numbers of 0s or 1s for the 64 presentations by 100.

To minimize the masking variance from individual differences, each subject was employed as his or her own control. These scores were calculated by dividing the score for each alpha period for each stimulus by the mean of all the scores for the alpha periods for the 64 presentations for each subject. These relative ratios of alpha periods were employed as the data for the majority of the analyses.

The basic design was a six-way analysis of variance with one level not repeated (sex) and five within subject levels. They were: 1) left vs right hemisphere of EEG measurement; 2) familiar vs unfamiliar figures; 3) the first half vs the second half of the experiment; 4) upper vs lower visual (tachistoscopic) field; and 5) left vs right visual (tachistoscopic) field. *Post hoc* (Tukey's, $p < .05$) and/or paired *t*-tests, depending upon interactions between within subject measures only, or interactions between within and between subject measures, were completed by calculating the appropriate combinations of aggregates that were revealed as statistically significant ($p < .05$) by the analyses.

RESULTS

The means and standard deviations (in parentheses) for the percentage of alpha periods (2-s windows that contained at least 1 s of alpha rhythms) for all 64 stimuli for each of the lobes were occipital: 21 (19)%; temporal: 13 (18)%, and parietal: 19 (18)%. A one-way analysis (within subjects) of variance showed a statistically significant difference in the percentage of alpha periods between the lobes [$F(2,34) = 4.62$, $p < .05$; eta-squared = 20%] during the stimulus presentations. *Post hoc* analysis (paired *t*-tests) indicated that the mean percentage of alpha periods over the temporal lobes was significantly ($t = 2.12$, $p < .05$) less during the entire experiment than the percentages over the parietal and occipital lobes that did not differ significantly from each other.

The results of the MANOVA for the relative ratios of alpha periods over the left and the right hemisphere for the occipital, parietal, and temporal lobes during the presentation of familiar or unfamiliar figures to the four quadrants of the tachistoscope during the first half and second half of the experiment demonstrated several statistically significant ($p < .01$) main effects and interactions. They will be presented, starting with the largest effect sizes (eta-squared values, i.e., the amount of variance explained) for each of the lobes.

The most powerful effect was the discrepancy in relative ratios of alpha periods for stimulus presentations over the temporal lobes. As noted in Figure 1, the relative ratios of alpha periods were

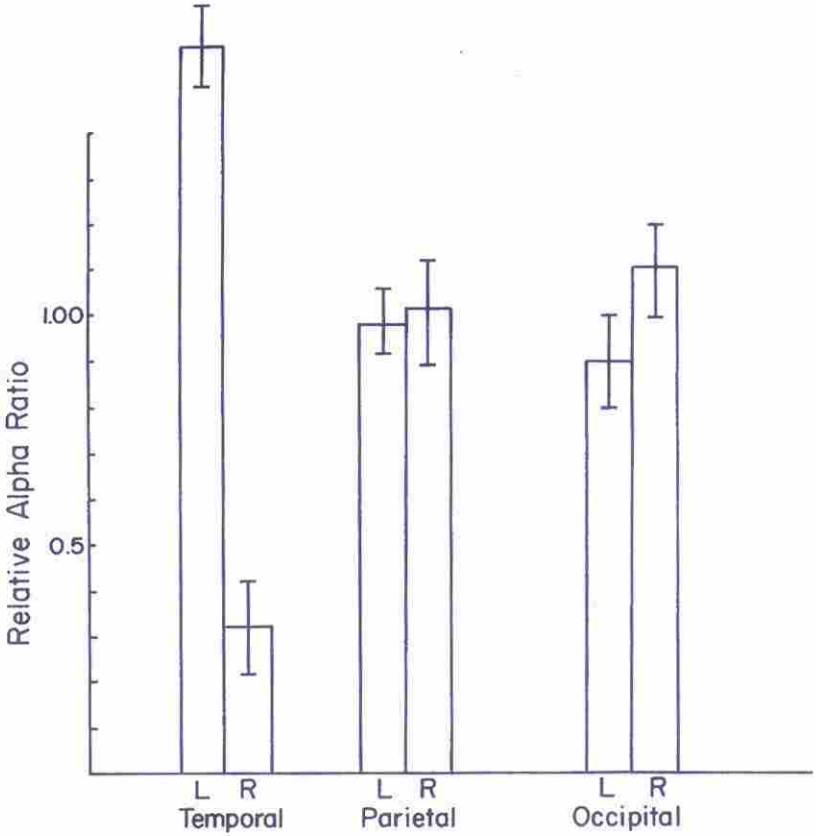

FIGURE 1. Relative ratios of numbers of periods with alpha rhythms (alpha periods) over the left and right hemispheres for the temporal, parietal, and occipital lobes during 64 presentations of figures for 18 subjects.

significantly less [$F(1,16) = 49.14$, partial eta-squared = 75%] over the right hemisphere compared to the left hemisphere. This hemispheric asymmetry during the exposure to all 64 slides, regardless of complexity or quadrant of presentation was not observed for either the parietal or the occipital lobes [$Fs(1,16) < 1.00$].

The second major effect was measured between the relative ratios of alpha periods displayed during the presentation of familiar or unfamiliar figures. As shown in Figure 2, the relative ratios of these periods following presentations of unfamiliar figures was

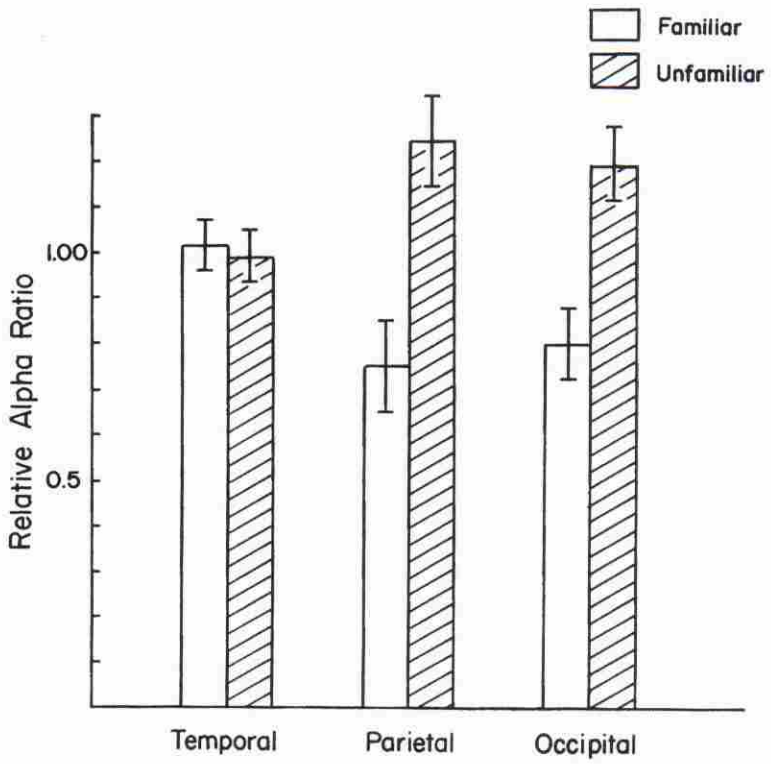

FIGURE 2. Relative ratios of numbers of alpha periods over the temporal, parietal, and occipital lobes during the 2-s intervals following presentations of either familiar or unfamiliar Kimura figures.

significantly greater over the parietal lobes [$F(1,16) = 6.97$, eta-squared = 30%) and the occipital lobes [$F(1,16) = 7.01$, eta-squared = 31%) relative to these ratios during presentations of familiar figures. The discrepancy between ratios of alpha periods during presentations of familiar and unfamiliar figures was not significant over the temporal lobes [$F < 1.00$].

A statistically significant three-way interaction between the left and right hemispheres, familiarity or nonfamiliarity, of the figures and their presentation to the upper or lower visual fields was shown for the occipital lobes [$F(1,16) = 9.05$, eta-squared = 36%] for the ratios of alpha periods. *Post hoc* analysis (means and SEMs for

which are shown in Table 1) indicated that the major source of this interaction was due to the greater proportion of relative ratios of alpha periods over the right hemisphere of the occipital lobe following presentations of unfamiliar figures to the lower visual field compared to the much faster activation (smaller relative ratios of alpha periods) over the right hemisphere when familiar figures were presented to the lower visual field. On the other hand, the activity was faster over the left hemisphere when familiar stimuli were presented in the upper visual fields compared to the presentation of unfamiliar stimuli presented to the upper visual field. This interaction was not statistically significant for either the temporal or parietal lobes.

There was a statistically significant interaction [$F(1,16) = 12.89$, eta-squared = 44%] between sex, presentation of the stimuli during the first and second half of the experiment, the familiarity or unfamiliarity of the stimulus figures, and their presentation in the left or right or upper or lower tachistoscopic field in the relative ratios of alpha periods for the parietal lobes only. *Post hoc* analysis of this five-way interaction, for which the means and standard errors of the mean are presented in Table 2, showed 1) that the source was primarily due to the greater activation (as defined by less, relative alpha ratios) over the left hemisphere for women compared to men for familiar figures within the lower right visual field during the first half of the experiment, relative to the women's maintained activity over the left hemisphere, and 2) increased activity over the

TABLE 1. Relative ratios of alpha periods over the right (R) or left (L) parietal or occipital lobes following the presentation of familiar (F) or unfamiliar (UF) figures to the upper (U) or lower (L) visual field.

			Occipital	
Hemisphere	*Figure*	*Field*	*M*	*SEM*
L	F	U	0.59	0.11
L	F	L	0.76	0.20
R	F	U	0.79	0.14
R	F	L	0.59	0.14*
L	UF	U	0.95	0.18
L	UF	L	0.85	0.15
R	UF	U	0.88	0.13
R	UF	L	1.15	0.20*

*Primary source of interaction.

TABLE 2. Relative ratios of alpha periods over the parietal lobes for the left and right hemisphere, during the first and second half of the experiment for familiar (F) or unfamiliar (U) figures presented to the upper left (UL), upper right (UR), lower left (LL), or lower right (LR) for men (M) and women (W)

	Left hemisphere				*Right hemisphere*			
				First half				
	F	U	F	U	F	U	F	U
	UL	UL	UR	UR	UL	UL	UR	UR
W	.41	.31	.05	.72	.38	.59	.21	.51
M	1.04	.98	.64	.80	1.10	1.57	.72	.75
	F	U	F	U	F	U	F	U
	UL	UL	UR	UR	UL	UL	UR	UR
W	.41	1.03	.00*	1.16	.21	1.08	.43	.77
M	.81	.94	.80*	1.10	.76	1.10	.32	.88
				Second half				
W	.40	.61	.37	.34*	.30	.95	.48	.41*
M	.99	.49	.76	1.76*	1.02	.42	.61	1.59*
	F	U	F	U	F	U	F	U
	UL	UL	UR	UR	UL	UL	UR	UR
W	.56	.72	.20	.67	.73	1.26	.78	.41
M	.50	.78	.72	.97	.22	.61	.83	.71

**Post hoc* pair difference $p < .05$.

right hemisphere, relative to men for unfamiliar figures presented to the upper right visual field during the second half of the experiment.

There were two additional major interactions between the within subject measures and gender. The first and most conspicuous interaction was between gender, cerebral hemisphere (left vs right), and the field (lower vs upper) of tachistoscopic presentation [$F(1,16) = 9.05$, eta-squared = 36%] for the occipital lobes. As noted in Figure 3, *post hoc* (selective paired *t*-tests for each gender) showed that the major source of the interaction was due to the disproportionately greater relative ratios of alpha periods over the right hemisphere for the men compared to the women when stimulus figures were presented to the upper (left or right) visual fields.

The second statistically significant interaction between sex and hemisphere [$F(1,16) = 6.07$, $p < .02$] for the relative ratios of alpha periods was observed for the temporal lobes. *Post hoc* analysis indicated that this source was due to the greater discrepancy between

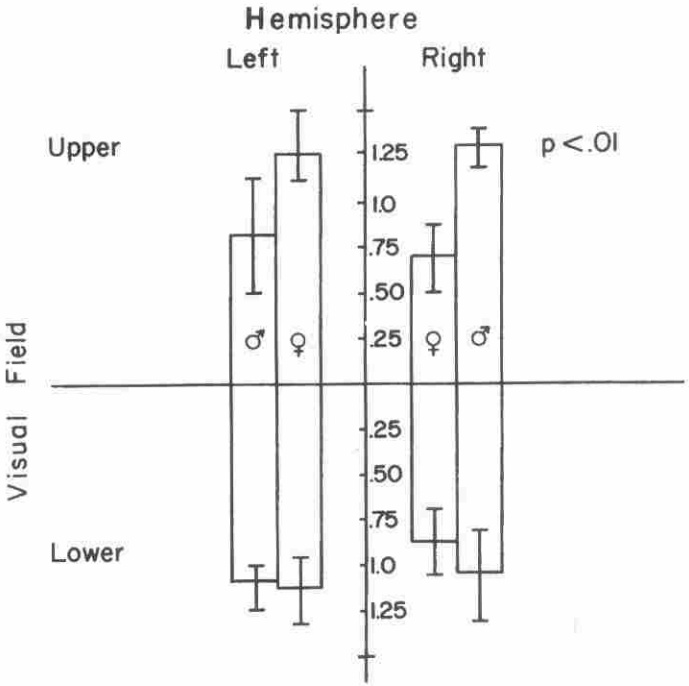

FIGURE 3. Relative ratios for alpha periods for men (n = 9) and women (n = 9) over either the left or right occipital lobes during the 2-s intervals after Kimura figures were presented to either the upper or lower tachistoscopic fields.

the left (M = 1.79, SEM = 0.15) and right (M = 0.18, SEM = 0.13) hemispheres for men compared to the women's values for the left (M = 1.45, SEM = 0.12) and right (M = 0.47, SEM = 0.13) hemispheres. There were no statistically significant interactions between sex and hemisphere for either the parietal or the occipital lobes.

DISCUSSION

The functional asymmetry of the different hemispheres and the different functions associated with the different lobes have been considered causal factors for the emergence of many of the properties of human experience. Traditional studies involved with the detection of visual stimuli have utilized letters or simple figures and have

measured response times (Gordon & Carmon, 1976). Modern experiments have employed the use of fMRI (functional magnetic resonance imaging) or PET (positron emission tomography) to infer the regions of the brain correlated with the experience of these stimuli.

The results of the present study indicated that careful and quantitative measurement of traditional electroencephalographic records when normal people are viewing complex figures can also reveal powerful cerebral asymmetries that are consistent with known functions of the human brain. The requirement to reference the measures of brain activity to the individual, i.e., to employ each person as his or her own control, in order to extract these powerful effects, would be expected in light of the marked individual differences in EEG patterns. Such standardization to the individual is typical for data obtained by fMRI or PET; the raw data obtained by these techniques are transformed to z-scores and compared to the subject's measures for control activities.

The first and most powerful effect found in the present study was the conspicuous increased electrical activity, as inferred by the marked reduction in alpha rhythms over the right temporal lobe compared to the left during the presentation of all 64 Kimura figures. The involvement of the right temporal lobes for procedures involving the memory for complex spatial patterns is consistent with the general functions of this region of the brain (Kolb & Whishaw, 1990; Kosslyn et al., 1989) and might reflect the increased activity associated with the representations required for long-term memory and consolidation. This marked laterality in activation accommodated about three-quarters of the variance in relative alpha ratios (scores obtained by dividing the presence or absence of an alpha period following each stimulus figure by the average of these periods for all figures) and is within the range of magnitude expected for a property that is observable even in clinical populations during qualitative examinations.

The second most powerful effect that suggested heterogeneity of responsivity within the lobes was the differential activation of the parietal and occipital lobes to the unfamiliar and familiar figures. Familiar figures produced greater activation over both the occipital and parietal regions compared to unfamiliar figures. This discrepancy was not observed for the temporal lobes. The occurrence of

this activation for the parietal and occipital lobes, but not for the temporal lobes, would be consistent with the role of the parietal and occipital lobes in the detection (rather than representation) of novel or non-novel stimuli presented within relatively brief time frames.

In the present study, the familiar and unfamiliar stimuli were all presented within about 6 min after the exposures to the priming stimuli. One would expect that the representations of the familiar figures to still be present within the occipitoparietal regions during this brief time, such that the subsequent repeated presentations (about once every 10 to 30 s) of familiar stimuli might reinforce the activity of the neurons associated with this representation. On the other hand, the temporal regions would not have been activated differentially to the two types of figures because both forms would still be entering the stages of consolidation.

The three-way interaction noted in Table 1 for the occipital lobe only would be consistent with the beginning of the intercalation between the two hemispheres in response to the repeated presentation of some figures but not others. Familiar stimuli (compared to the nonfamiliar stimuli) presented to the upper field produced about twice the activity over the left occipital lobe, while presentation of familiar stimuli (compared to nonfamiliar stimuli) to the lower visual field produced about twice the activity over the right occipital lobe compared to other combinations where the discrepancies between familiar and unfamiliar stimuli were not statistically significant. This anistropic activation for the upper and lower field would be expected if pathways associated with the right parietotemporal region (for detection and memory) were being coactivated with the initial stages of verbal labeling through the occipitotemporal regions within the left hemisphere.

In light of the magnitude of differences in lateralization and the slight disparities of function within lobes reported for normal men and women (e.g., Corsi-Cabrera et al., 1989), sex differences within tachistoscopic studies would be expected to emerge as interactions between visual quadrants, hemisphere of activation, and familiarity of the stimuli. We have found that despite the general male proficiency and speed for visuospatial tasks, the male's spatial memory for spatial patterns is often less proficient than the memory displayed by females.

The relatively greater activity of the left parietal lobe for women for familiar figures compared to unfamiliar figures presented to the lower right visual field (Table 2) would be consistent with classical relationships between the lower right visual field and the left parietal region. It would also be congruent with the observations by Corsi-Cabrera et al. (1989) who found greater coherence between the two parietal lobes for women compared to men. Such coherence may have allowed more interaction between the left and right parietal lobes for women relative to men. Effectively, there was no alpha activity, only beta activity, over the left parietal lobes for the women when familiar figures were presented to the lower right field during the first half of the experimental series.

The source of the four-way interaction may have been due to the change in the activity over both the right and left parietal lobes of the men for unfamiliar figures presented in the upper right visual field during the second half of the series. Compared to the women, the men showed marked increases in relative alpha activity to the unfamiliar figures. This marked difference could reflect a general habituation to the repeated presentation of different, novel stimuli for the men (Makarec & Persinger, 1995).

Because the effects were associated with unfamiliar stimuli presented to the upper right visual field, which is often associated with activity within the left occipitotemporal region, the manifestation of the change over the left and right parietal regions for the men could suggest a more limited capacity for the male brain to represent *where* unfamiliar patterns are in space when the short-term representation capacity within the left occipitotemporal region, associated with language, is repeatedly challenged. We have found that such challenges for the lateralized brain, such as bilingualism in university men, affect verbal memory, but not spatial memory, and accuracy for the left ear during dichotic word listening. Bilingual men recalled about 20% to 40% less verbal memory (Makarec & Persinger, 1993) and committed about twice the numbers of left ear errors compared to bilingual women who did not differ from either monolingual men or women (Persinger et al., 2002).

The effect shown in Figure 3 was also associated with an interaction between sex and activity over the left and right occipital lobes. The source of the interaction was primarily due to the significant

disparity in relative activity between the left and right occipital lobes for the women when the figures were presented to the upper visual fields. This anistropy suggests that temporo-occipital activity remained greater over the right occipital lobe compared to the left for the women only, and again would be consistent with a greater contribution of temporal lobe processes, such as memory, to the enhanced vigilance displayed by women (Persinger & Richards, 1995; Richard et al., 1992).

Finally, the weakest but still statistically significant interaction involving sex was noted for the activity in the left and right temporal lobes. The interaction was due to the greater difference in relative activity over the left temporal lobes compared to the right temporal lobes for the men compared to the women. This degree of lateralization was less for the women than for the men. If the difference between the ratios for the left and right temporal lobes for the men and women are obtained and the values for the men are divided by this value for the women, then the men displayed about 60% more lateralization than did the women. Inversely, the women showed about 40% more coherence in the proportion of alpha rhythms between the two temporal lobes compared to the men. These small differences would be consistent with the more direct measurements by Corsi-Cabrera et al. (1989) and the implications of the hypothesis of vectorial cerebral hemisphericity (Persinger, 1993). This suggests that conditions facilitating intercalation between the two hemispheres increase the incidence of awareness by the left hemisphere of subtle information usually maintained within right hemispheric processes.

In conclusion, the results of this study clearly indicated that objective measurements of visually discernable alpha periods during the 2 s following presentations of Kimura figures to the various quadrants of the visual fields can produce specific changes within the electroencephalographic activity over the two hemispheres. The effects were quantitatively powerful in terms of explaining the variance in the ratios of relative activity and were consistent with what is known about cerebral lateralization and the important contribution of variance from gender differences when more complex experimental designs are employed to understand cerebral function.

REFERENCES

Brown, H. D., & Kosslyn, S. M. (1995). Hemispheric differences in visual object processing: structural versus allocation theories. R. J. Davidson & K. Hugdahl, Eds., *Brain asymmetry*. Cambridge, MA: MIT Press, pp. 77–97.

Corsi-Cabrera, M., Herrera, P., & Malvido, M. (1989). Correlation between EEG and cognitive abilities: Sex differences. *International Journal of Neuroscience, 45*, 133–141.

Gordon, H. W., & Carmon, A. (1976). Transfer of dominance in speed of verbal response to visually presented stimuli from right to left hemisphere. *Perceptual and Motor Skills, 42*, 1091–1100.

Hellige, J. B. (1995). Hemispheric asymmetry for components of visual information processing. In R. J. Davidson & K. Hugdahl, Eds., *Brain asymmetry*. Cambridge, MA: MIT Press, pp. 99–121.

Kimura, D. (1986). *Neuropsychological test procedures*. London, Ontario: DK Consultants.

Kolb, B., & Whishaw, I. Q. (1990). *Fundamentals of human neuropsychology*, 3rd ed. New York: Freeman.

Kosslyn, S. M., Koenig, O., Barrett, A., & Cave, C. B. (1989). Evidence for two types of spatial representations: Hemispheric specialization for categorical and coordinate relations. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 723–735.

Makarec, K., & Persinger, M. A. (1993). Bilingual men but not women displayed verbal memory but not figural memory weaknesses compared to monolinguals. *Personality and Individual Differences, 15*, 531–536.

Makarec, K., & Persinger, M. A. (1995). Complex partial epileptic-like signs and differential visual search times for normal men and women: Implications for functional lateralization. *Personality and Individual Differences, 18*, 643–651.

Persinger, M. A. (1993). Vectorial cerebral hemisphericity as differential sources for the sensed presence, mystical experiences and religious conversions. *Perceptual and Motor Skills, 76*, 915–930.

Persinger, M. A., & Richards, P. M. (1995). Women reconstruct more details than men for a complex five-minute narrative: Implications for right hemispheric factors in the serial memory effect. *Perceptual and Motor Skills, 80*, 403–410.

Persinger, M. A., Chellew-Bellanger, G., & Tiller, S. G. (2002). Bilingual men but not women display less left ear but not right ear accuracy during dichotic listening compared to monolinguals. *International Journal of Neuroscience, 112*, 69–77.

Richards, P. M., Koren, S. A., & Persinger, M. A. (1993). Experimental stimulation by burst-firing weak magnetic fields over the right temporal lobe may facilitate apprehension in women. *Perceptual and Motor Skills, 75*, 667–670.